SECTION 2.0
MIXING ZONE DISPERSION ANALYSIS

Amoco proposes to install a multiport diffuser for the discharge of treated effluent from Outfall 001. Though it is not necessary to satisfy Indiana mixing zone demonstration requirements, the use of a multiport diffuser provides an additional amount of environmental protection by ensuring more rapid and immediate mixing than is provided by the existing outfall.

2.1 MULTIPORT DIFFUSER MODELING

Amoco has evaluated a proposed diffuser location (Site S3500) in Lake Michigan as shown in Figure 2-1. The rationale for this site is to maximize mixing with ambient waters by locating the diffuser in deeper waters where more water volume is available for rapid mixing than is available at the current Outfall 001. Site S3500 is located in Lake Michigan approximately 3,500 ft from the current Outfall 001 in water depths measured at 28 to 30 ft. Specific benefits of a multiport diffuser at this location include:

1) The diffuser, by design, provides even more rapid and immediate mixing in a small area.
2) The diffuser would be located offshore, thereby minimizing plume contact with Lake Michigan shoreline.
3) The diffuser site would be exposed to the general nearshore current/circulation patterns that enhance local mixing.
4) The discharge would be present in deeper waters completely submerged and surrounded by lake water available for entrainment (induced mixing). Vertical mixing throughout the water column would be achieved as the positively buoyant plume rises toward the surface.

In order to evaluate the dispersion and size of a mixing zone from a multiport diffuser, the USEPA-endorsed computer model CORMIX, developed by Dr. Gerhard Jirka at Cornell University, was used for analysis. Specifically, the CORMIX2 expert system was utilized to determine achievable dispersion at the edge of the Jet Entrainment Zone, the Near-

Field Zone, and the Far-Field Zone. CORMIX2 calculates plume characteristics (i.e., dispersion, plume width) for specific regions (modules) of the mixing zone which are defined by discharge and ambient water classification criteria. The specific regions are linked together by transition equations resulting in a complete projection of the plume up to a user-specified distance. Although several computer models are listed in the USEPA 1991 TSD, CORMIX2 has been commonly used by regulators as a useful analysis tool for NPDES permitting. CORMIX2 was also selected because it integrates both near-field and far-field projections with customized transition equations. The CORMIX2 model also features additional sensitivity to receiving water boundaries. CORMIX2 provided the model estimates given in the remainder of this report. As noted in Attachment 1, computer models usually underestimate achievable dispersion. This overestimate of exposure leads to a conservative estimate of the evaluation of risk impact.

2.1.1 Model Input Parameters and Diffuser Design

The main criterion for development of an effective diffuser design is to maintain a specific port exit velocity at the average effluent flowrate. The USEPA 1991 TSD recommends maintaining a 10 ft/sec port exit velocity to ensure rapid mixing. If the effluent flow rate and exit velocity are known, the port diameter can be determined for a selected number of diffuser ports. Table 2-1 presents various configurations for a diffuser discharging the average Outfall 001 flowrate of 13 mgd. For this analysis, a 90-ft diffuser (approximate length) with ten 6-in diameter ports spaced 10 ft apart was chosen as an appropriate design for the Amoco discharge (see Attachment 2). The diffuser is unidirectional with all 10 ports pointing toward the center of the lake (due north, away from shore). The 6-in diameter ports and 10-ft port spacing provide standard dimensions for ease of installation and still maintain a 10 ft/sec exit velocity (actually calculated as 10.3 ft/sec). Other configurations could be used for final design; however, port diameters should not be too small where clogging from debris might occur and spacing should be large enough where immediate entrainment of adjacent ports is avoided. Modeling results for various diffuser designs (Table 2-1) revealed slight differences in jet entrainment zone dispersion for alternate design configurations, yet were within the relative range of accuracy of the model of the 10 port design.

Table 2-2 presents the remaining input parameters for the CORMIX2 simulations. Bathymetry measurements taken May 11, 1994 verified that Site S3500 is located at a lake depth of 28.5 ft. Long-term average effluent and lake temperatures revealed an annual average temperature difference of 17 °C. The effluent plume is usually warmer than the receiving water and a temperature difference of 20 °C was used in the model. Field measurements of lake temperature and conductivity taken during the long term bioassessment program (1994 to 1997), as shown in Table 2-3, revealed no significant temperature or conductivity gradients (i.e., no thermal stratification) in the Lake Michigan at the S3500 location. Furthermore, field measurements of conductivity confirmed that differences between the effluent and lake were negligible with respect to density in fresh water. Therefore plume buoyancy is driven solely by temperature differences. The positively buoyant condition (effluent temperature greater than receiving water temperature by 20 °C) resulted in the use of a 0 degree (horizontal) port discharge angle, where the plume rises to the surface and is exposed to the full vertical water column.

Lake velocity (current) in nearshore Lake Michigan is influenced by several forces (primarily wind) and changes in both speed and direction. Ambient velocity is a significant mixing force, especially in the far-field zone, as increased lake velocity will increase plume dispersion. Localized wind currents and along-shore physical features create a continuously dynamic condition in the lake. For the location of S3500, wind currents provide the predominant transport mechanism. Based on Midway Airport meteorological data compiled by NOAA (Attachment 3), the prevailing wind direction for the south end of Lake Michigan is out of the south at an average speed of around 10 knots. A general engineering rule for estimating lake currents generated by surface wind is to multiply the wind speed by one-thirtieth (1/30) to obtain the wind-induced lake velocity. Therefore, this would result in an average lake velocity of around 0.18 m/sec (0.59 ft/sec). A summary of measured nearshore Lake Michigan currents, primarily for Argonne National Laboratory studies conducted in the Calumet area, is presented in Table 2-4. For purposes of this analysis, a condition representing conservative lake velocity (0.10 m/sec) was used. The 0.10 m/sec lake velocity is less than velocity values derived from prevailing wind data and is consistent with the range of actual measured values.

2.1.2 Model Results

For the input parameters described above, model runs were conducted for dispersion estimation as a function of distance from the diffuser at S3500. The model output is given in Attachment 4 and graphically presented in Figure 2-2. At S3500, the plume is projected to be fully vertically mixed in the jet entrainment zone (per CORMIX2 classification) and extends to a distance of one-half of the diffuser length (45 to 50 ft). The one-half to one diffuser length distance provides a conservative guide for establishing the extent of the jet entrainment zone, or the Discharge-Induced Mixing Zone (DIMZ) (1980 Lee and Jirka). The dispersion projected at this distance is 54:1 for S3500. As discussed in Section 1, the USEPA's 1991 TSD states that if the travel time through the acute mixing zone (DIMZ) is less than 15 minutes, then the AAC (based on one-hour exposure) is not exceeded. CORMIX2 projects a time of plume travel of less than 90 seconds to reach the edge of the DIMZ (45 to 50 ft).

After the jet entrainment zone, the CORMIX2 model projects a transition zone that is "insignificant in spatial extent and will be bypassed" (see CORMIX Model output, Attachment 4). Therefore, there is no additional dispersion gained in the transition zone and the extent of the Near-Field Zone is equal to the extent of the DIMZ. At the DIMZ, the extent of discharge-induced mixing is equal to 45 to 50 ft from the diffuser where a dispersion of 54:1 is achieved. Since Indiana law limits the mixing zone to the DIMZ for a Lake Michigan discharger, Amoco proposes a mixing zone of 50 feet around the diffuser structure.

Past the Near-Field Zone, physical mixing continues, and CORMIX2 dispersion projects into the Far-Field Zone up to a user-specified distance of 3,300 ft. The actual extent of the Far-Field Zone, used for regulatory application is determined from regulatory definitions, not from hydrodynamic principles since the plume will continue to disperse at the molecular level over great distances. The 1991 TSD suggests that the DIMZ occupy 10 percent of the far-field zone, therefore, an appropriate far-field distance of 500 ft can be established for the Amoco diffuser. At this distance, CORMIX2 projects an effluent dispersion of 77:1 for the far-field zone. A total mixing zone of 500 feet radius around the diffuser structure is consistent with USEPA approaches to protecting the environment.

2.2 SUMMARY

The mixing zone dispersion analysis for a multiport diffuser located at S3500, conducted in accordance with USEPA guidance, shows that the proposed discharge configuration adds a margin of safety to protect the quality of the receiving waters compared to the existing outfall structure. This enhanced environmental protection is due to the rapid and immediate mixing that occurs within a small area as a result of the diffuser.

TABLE 2-1. PORT SIZES AND SPACING FOR A 90-FT MULTIPORT DIFFUSER

NUMBER OF PORTS	EFFLUENT FLOW (mgd)	EFFLUENT FLOW (cfs)	EXIT VELOCITY (ft/sec)	PORT AREA (sq ft)	PORT DIAMETER (in)	DIFFUSER PORT SPACING (ft)
1	13.0	20.1	10	2.01	19.2	
2	13.0	20.1	10	1.01	13.6	90.0
3	13.0	20.1	10	0.67	11.1	45.0
4	13.0	20.1	10	0.50	9.6	30.0
5	13.0	20.1	10	0.40	8.6	22.5
6	13.0	20.1	10	0.34	7.8	18.0
7	13.0	20.1	10	0.29	7.3	15.0
8	13.0	20.1	10	0.25	6.8	12.9
9	13.0	20.1	10	0.22	6.4	11.3
10	13.0	20.1	10	0.20	6.1	10.0
11	13.0	20.1	10	0.18	5.8	9.0
12	13.0	20.1	10	0.17	5.5	8.2
13	13.0	20.1	10	0.15	5.3	7.5
14	13.0	20.1	10	0.14	5.1	6.9
15	13.0	20.1	10	0.13	5.0	6.4

Note:
10-port diffuser selection based on design experience.

TABLE 2-2. CORMIX2 MODEL INPUT PARAMETERS

PARAMETER	VALUE	RATIONALE
Effluent flow	13 mgd	Long term average
Port exit velocity	10.3 ft/sec	EPA TSD recommendation
Number of ports	10	Standard design (Table 2-1)
Port diameter	6 in	Standard design (Table 2-1)
Diffuser length	90 ft	Standard design (Table 2-1)
Port spacing	10 ft	Standard design (Table 2-1)
Port discharge angle	0 degrees	Optimizes plume buoyancy
Diffuser height off bottom	1.6 ft (0.5 m)	Practical estimate
Effluent temperature	30 °C	Long term average = 28 °C
Lake temperature	10 °C	Long term average = 11 °C
Temperture difference	20 °C	Conservative input (average = 17°C)
Minimal lake velocity	0.33 ft/sec (0.10 m/sec)	Conservative input (average = 0.59 ft/sec)

In each case, selection of each parameter value was made to result in smaller dispersion values than would have been calculated with average values. The aggregate result is that the dispersion in Lake Michigan is underestimated herein.

TABLE 2-3. LAKE MICHIGAN WATER QUALITY DATA

Temperature (°C)															
Date	5/10/94	5/23/95	5/24/95	5/25/95	5/23/95	5/24/95	5/25/95	6/5/96	10/21/96	10/24/96	10/21/96	10/22/96	4/28/97	4/28/97	4/29/97
Location	S3500	C3501	C3501	C3501	S3500	S3500	S3500	S3500	C3501	C3501	S3500	S3500	C3501	S3500	S3500
Depth (ft)															
surface	11.87	13.3	13.3	13.7	14	13.3	13.5	15	14.8	13.6	14.7	15.1	9.7	10.7	8.5
2 to 3				13.7	14			15	14.8	13.6	14.7	15.1	9.7	10.7	8.5
5 to 6	11.87	13.3	13.3	13.7	13.3	13.3	13.5	15	14.8	13.6	14.7	15	9.1	10.7	8.5
8 to 9	11.85			13.7	13.2		13.5	14	14.6	13.6	14.7	14.7	8.4	8.9	8.5
11 to 12	11.86	13.3	13.3	13.7	13	13.3	13.5	14	14.5	13.6	14.4	14.5	8.2	8.4	8.4
14 to 15	11.84	13.3	13.3	13.7	13	13.3	13.5	14	14.5	13.6	14.4	14.3	8	8.2	8.4
17 to 18	11.86			13.7	13		13.5	14	14.4	13.6	14.4	14.2	7.9	8.1	8.3
20 to 21	11.84	13.3	13.3	13.7	12.7	13.3	13.5	14	14.4	13.6	14.4	14.2	7.9	8	8.3
24 to 25	11.85			13.7	12.5		13.5	13	14.4	13.6	14.3	14.2	7.8	7.9	8.3
27 to 28		13.3	13.3	13.7	12.2	13.3	13.5	13	14.4	13.6	14.4	14.2	7.9	7.8	8.3

Conductivity (µmhos/cm)															
Date	5/10/94	5/23/95	5/24/95	5/25/95	5/23/95	5/24/95	5/25/95	6/5/96	10/21/96	10/24/96	10/21/96	10/22/96	4/28/97	4/28/97	4/29/97
Location	S3500	C3501	C3501	C3501	S3500	S3500	S3500	S3500	C3501	C3501	S3500	S3500	C3501	S3500	S3500
Depth (ft)															
surface	285	301	295	298	301	291	289	300	308	294	306	299	313	318	291
2 to 3				290	299			301	308	294	309	298	313	317	286
5 to 6	285	296	292	290	296	298	289	304	308	291	305	298	311	315	287
8 to 9	285			291	296		290	297	306	294	305	297	303	306	291
11 to 12	285	289	289	292	295	301	290	305	305	298	301	294	303	303	290
14 to 15	285	305	293	291	296	300	292	300	305	294	304	292	301	304	290
17 to 18	285			294	297		289	300	304	294	301	289	301	303	278
20 to 21	285	300	301	293	296	297	296	300	300	288	302	289	300	300	290
24 to 25	284			293	294		294	300	300	289	300	289	300	298	294
27 to 28		306	301	292	294	297	280	302	300	294	300	289	300	298	297

TABLE 2-4. SUMMARY OF LAKE MICHIGAN CURRENT MEASUREMENTS

REFERENCE	DATE	FREQUENCY	NUMBER OF CURRENT METERS	CURRENT METER LOCATION	DEPTH	RESULT
Snow 1974	Nov. 8 to Dec. 8, 1973	20 min	3	At 68th St. Crib (1) Off Inland landfill (2)	5.2m (1) 3m and 6m (2)	Typical lake currents on the order of 0.05 to 0.15 m/sec
Saunders 1976	June 23 to Dec. 22, 1975	Continuous	5	3 km offshore from South Water Filtration Plant (SWFP)	12 m (mid-depth)	Strong currents observed for Nov. 17 to Dec. 22 Speed range = 0.15 to 0.30 m/sec Maximum speed = 1.0 m/sec
McCown 1976	Feb. 11 to Feb. 17, 1976	40 min	3	3 km offshore from SWFP	1m off bottom	Maximum speed observed was 0.15 m/sec
Harrison 1977 McCown 1978	Jan. 4 to Mar. 26, 1977	8 min	4	3 km offshore between Indiana Harbor Ship Canal (IHSC) and SWFP	1.5 m off bottom	Average speed = 0.015m/sec Root-mean-square speed = 0.074 m/sec Maximum speed = 0.15 m/sec Significant ice cover present late Jan-early Feb.

REFERENCES

Snow, October 1974, "Water Pollution Investigation: Calumet Area of Lake Michigan. Volume 1", IIT Research Institute.

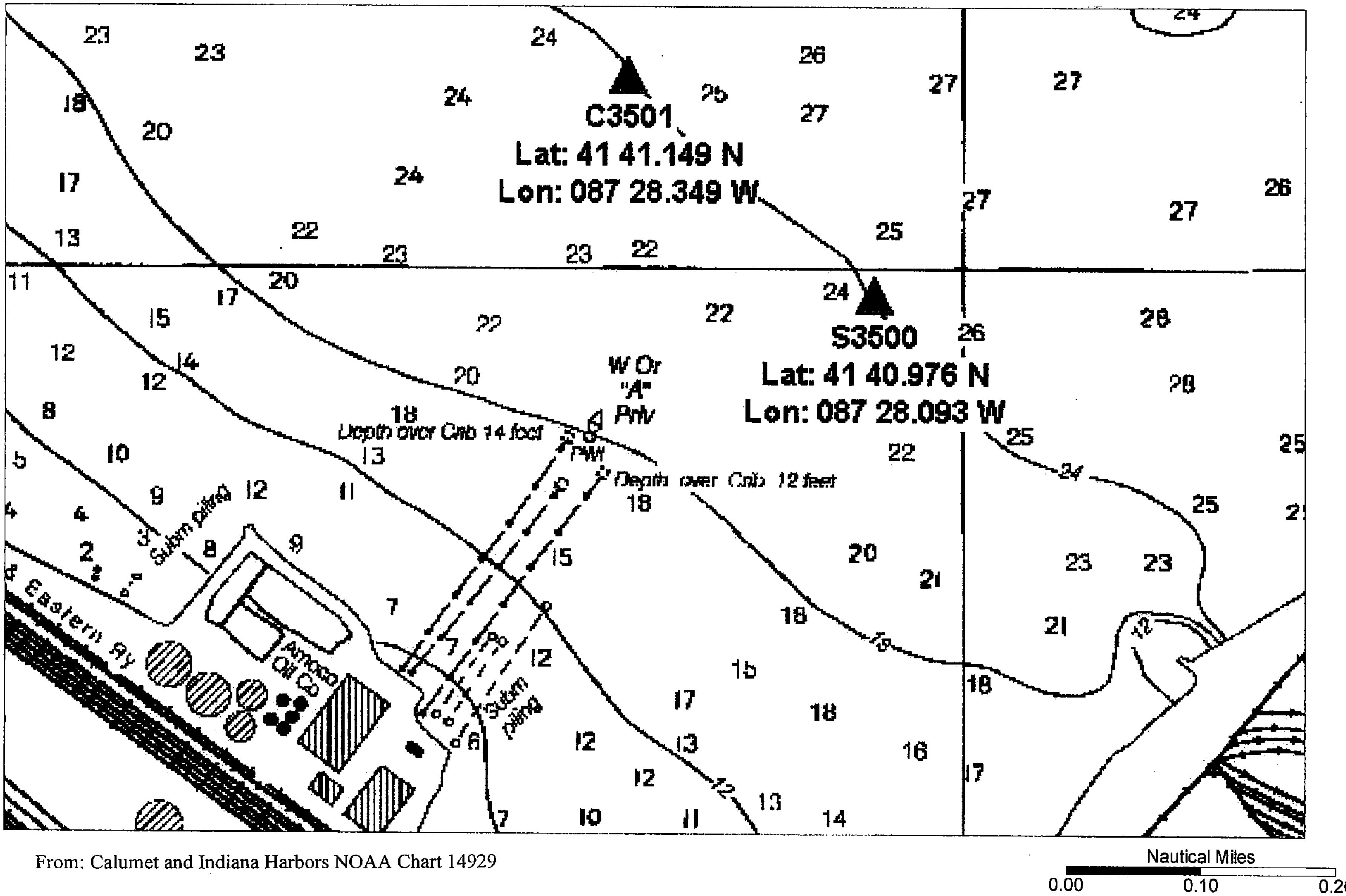
Saunders, et al., May 1976, "Nearshore Currents and Water Temperatures in Southwestern Lake Michigan (June - December, 1975)", Argonne National Laboratory (ANL).

McCown, et al., July 1976, "Transport and Dispersion of Oil Refinery Wastes in the Coastal Waters of Southwestern Lake Michigan (Experimental Design - Sinking Plume Condition)", ANL.

Harrison, et al, December 1977 "Pollution of Coastal Waters off Chicago by Sinking Plumes from the Indiana Harbor Canal", ANL.

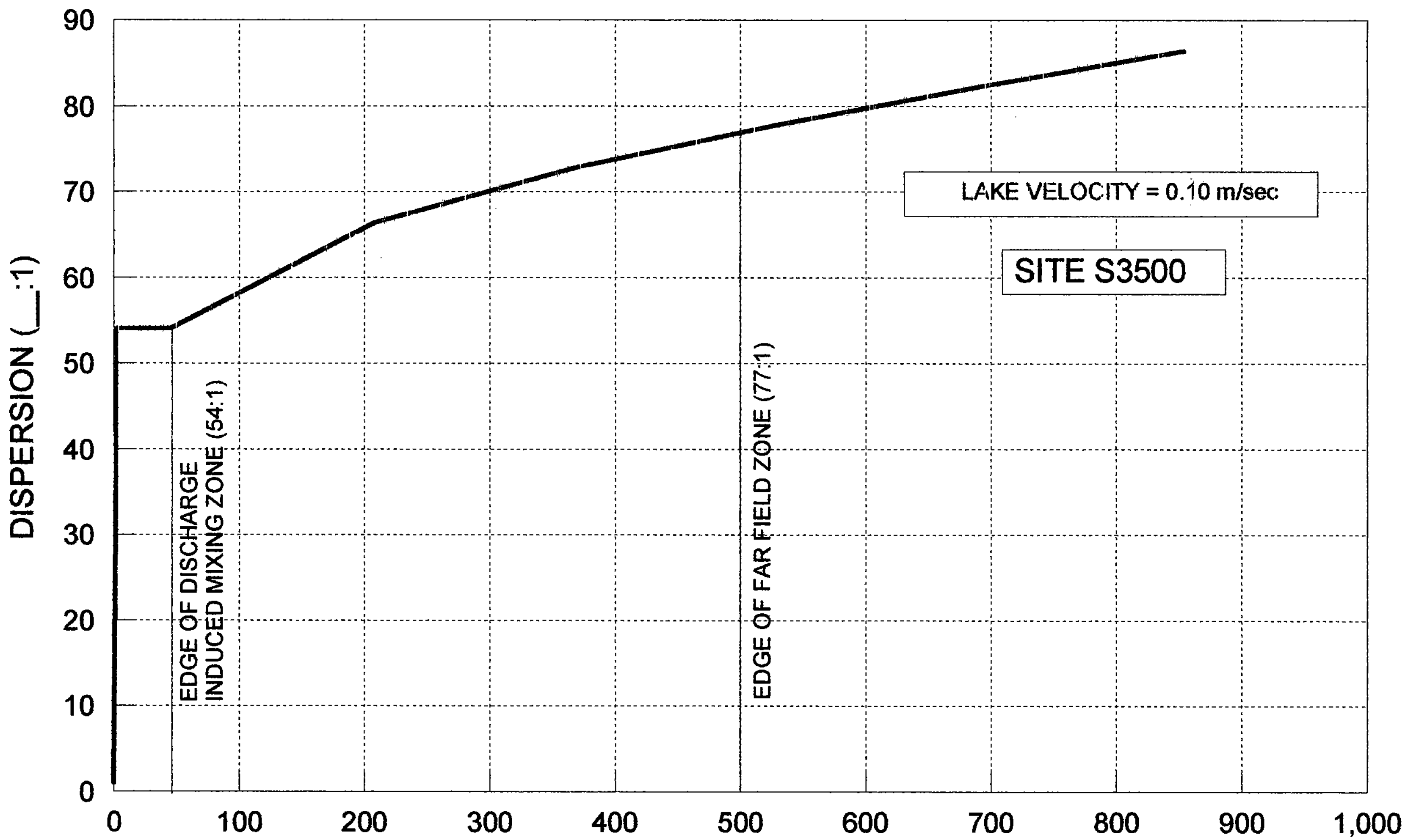
McCown, et al., November 1978, "Transport of Oily Pollutants in the Coastal Waters of Lake Michigan", ANL.

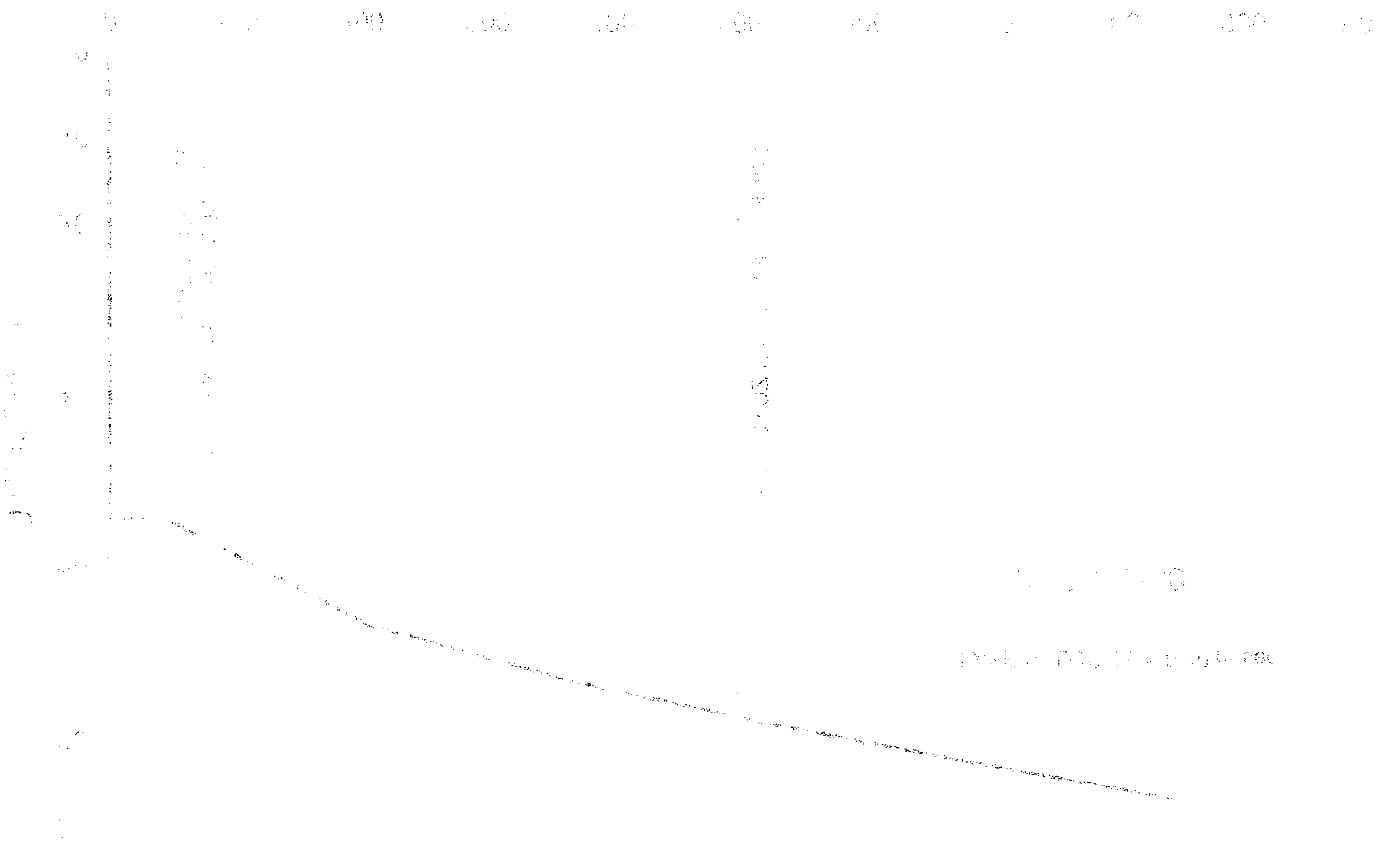
Figure 2-1
Water Depth at the Proposed Diffuser Location (S3500)



From: Calumet and Indiana Harbors NOAA Chart 14929

FIGURE 2-2. CORMIX2 RESULTS FOR MULTIPORT DIFFUSER





SECTION 3.0
MIXING ZONE DEMONSTRATION

3.1 INTRODUCTION

To grant a mixing zone, the permittee must provide specific information to assure that a mixing zone is appropriate for the discharge. The necessary information for a mixing zone demonstration has been described by USEPA guidance and Indiana state rules to determine the boundaries of the mixing zone, the magnitude of mixing, the impact of the mixing zone on the receiving water, and the steps taken to prevent acute impacts to aquatic life and prevent impairment of the use of the water as follows:

- 327 IAC 5-2-11.4(b)(4)(A)(i) - Document the characteristics and location of the outfall structure, including whether technologically enhanced mixing will be utilized.
- 327 IAC 5-2-11.4(b)(4)(A)(ii) - Document the amount of dilution occurring at the boundaries of the proposed mixing zone and the size, shape and location of the area of mixing, including the manner in which diffusion and dispersion occur.
- 327 IAC 5-2-11.4(b)(4)(A)(iii) - For sources discharging to the open waters of Lake Michigan, define the location at which discharge-induced mixing ceases.
- 327 IAC 5-2-11.4(b)(4)(A)(iv) - Document the physical including substrate character and geomorphology, chemical and biological characteristics of the receiving waterbody, including whether the receiving waterbody supports indigenous, endemic or naturally occurring species.
- 327 IAC 5-2-11.4(b)(4)(A)(v) - Document the physical, chemical, and biological characteristics of the effluent.
- 327 IAC 5-2-11.4(b)(4)(A)(vi) - Document the synergistic effects of overlapping mixing zones or the aggregate effects of adjacent mixing zones.
- 327 IAC 5-2-11.4(b)(4)(A)(vii) - Show whether organisms would be attracted to the area of mixing as a result of the effluent character.

- 327 IAC 5-2-11.4(b)(4)(B)(i) - The mixing zone would not interfere with or block passage of fish or aquatic life.

- 327 IAC 5-2-11.4(b)(4)(B)(ii) - The level of pollutant permitted in the waterbody would not likely jeopardize the continued existence of any endangered or threatened species listed under Section 4 of the ESA or result in the destruction or adverse modification of such species habitat.

- 327 IAC 5-2-11.4(b)(4)(B)(iii) - The mixing would not extend to drinking water intakes.

- 327 IAC 5-2-11.4(b)(4)(B)(iv) - The mixing zone would not impair of otherwise interfere with the designated uses of the receiving water or downstream waters.

- 327 IAC 5-2-11.4(b)(4)(B)(v) - The mixing zone would not promote undesirable aquatic life or result in a dominance of nuisance species.

- 327 IAC 5-2-11.4(b)(4)(B)(vi) - By allowing the additional mixing: (AA) substances will not settle to form objectionable deposits; (BB) floating debris, oil, scum, and other matter in concentrations that form nuisances will not be produced; and (CC) objectionable color, odor, taste, or turbidity will not be produced.

- 327 IAC 5-2-11.4(b)(4)(C) - In no case shall a mixing zone for a discharge into the open waters of Lake Michigan be granted that exceeds the area where discharge-induced mixing occurs.

This information is evaluated to assure that it is environmentally protective to use a mixing zone for the discharge and to define the point of application of receiving water quality standards. Also, to assist the Commissioner regarding additional information for assessing the mixing zone (based on aquatic life, human health, or wildlife), data and references are presented in Volume II (submitted August 1994) and in this revised volume.

Amoco proposes that a mixing zone be included in its renewed NPDES permit. The following discussion describes the physical, chemical, and biological characteristics of the receiving water (southern Lake Michigan). It also describes the Amoco Outfall 001 discharge at the proposed diffuser site. These characteristics are analyzed in the context of the specific points noted in Indiana 327 IAC 5-2-11.4(b)(4) to demonstrate that an appropriate mixing zone can be delineated in southern Lake Michigan consistent with Indiana rules and USEPA guidelines (1993 WQSH - Chpt 5, 1991 TSD - Chpt 2 & 4).

3.2 INDIANA MIXING ZONE REGULATORY REQUIREMENTS (327 IAC 5-2-11.4(b)(4))

As discussed in Attachment 1, the USEPA provides guidance on determining and assessing the applicability of mixing zone implementation for a discharge. As shown in Table A1-1, these USEPA specifications are incorporated into the Indiana Water Quality Standards. The following text presents the Indiana mixing zone demonstration regulatory language and Amoco's responses to the requirements.

<u>327 IAC 5-2-11.4(b)(4)(A)(i) - Document the characteristics and location of the outfall structure, including whether technologically enhanced mixing will be utilized.</u>

Technologically enhanced mixing will be provided by the use of a state-of-the-art high-rate multiport diffuser. A high-rate diffuser maximizes mixing and minimizes organism exposure time. The preliminary design of this diffuser (Attachment 2) includes the following characteristics:

- header length = 90 ft
- number of ports = 10
- port spacing = 10 ft
- port diameter = 6 in
- diffuser orientation = unidirectional with ports pointing due north (away from the shore toward the center of the lake)
- vertical port discharge angle = 0 degrees from horizontal
- diffuser height off lake bottom = 1.6 ft

The diffuser will be located about 3,500 ft northeast of the current Outfall 001 at latitude 87° 28.093'W and longitude 41° 40.976'N. These coordinates correspond to Station S3500 of the current long-term bioassessment program.

327 IAC 5-2-11.4(b)(4)(A)(ii) - Document the amount of dilution occurring at the boundaries of the proposed mixing zone and the size, shape and location of the area of mixing, including the manner in which diffusion and dispersion occur.

The dilution (dispersion) ratio has been optimized by modeling a high-rate submerged multiport diffuser located approximately 3,500 ft from the current Outfall 001. Dispersion estimates were derived from the USEPA-supported model CORMIX2 as discussed in detail in Section 2. Using conservative model input parameters, including plume buoyancy and lake velocity, CORMIX2 projected a DIMZ dispersion of 54:1 at a distance of one-half diffuser length (45 to 50 ft) from the diffuser. The CORMIX2 DIMZ is hydraulically equivalent to the extent of the Near-Field Zone. Far-Field projections indicated an appropriate dispersion of 77:1 achieved at a distance of 500 ft from the diffuser.

As mentioned previously, since the Outfall 001 diffuser will be a discharge to the open waters of Lake Michigan, the applicable mixing zone dispersion is capped, as per 5-2-11.4(b)(4)(C), at the point where discharged induced mixing ceases. Therefore, the applicable mixing zone dispersion and distance are reduced to the corresponding CORMIX2 DIMZ values (54:1 and 50 ft, respectively). The applicable mixing zone would directly utilize a 54:1 dispersion for calculating both acute and chronic wasteload allocation values as presented in 327 IAC 5-2-11.4(c).

Amoco proposes delineating a mixing zone that maintains a 50-ft distance from all points on the diffuser. One can envision the mixing zone plan-view shape as a "racetrack" surrounding the 90-ft-long diffuser; one 100 ft x 90 ft rectangle centered over the diffuser length and one semi-circle area (radius = 50 ft) at each end. For the mixing zone, the vertical profile would occupy the entire average water depth (28 ft) within this area. A mixing zone that completely surrounds the diffuser is necessary to accommodate lake velocities induced by winds of various directions. The mixing zone shape described above corresponds to lateral area of 0.39 acre. A conceptual sketch of the mixing zone is given in Figure 3-1.

The mixing zone area would be located about 3,500 ft northeast of the current Outfall 001 at longitude 87° 28.093'W and latitude 41° 40.976'N as shown in Figure 3-2. The mixing

zone would not overlap any adjacent mixing zones or outfalls. Furthermore, the mixing zone will not contact any shorelines or other receiving waters since they are greater than 50 ft away from the diffuser.

The manner in which diffusion and dispersion will occur is through rapid and immediate mixing of discharged effluent with Lake Michigan receiving water. The diffuser is designed to maintain the USEPA-recommended discharge exit velocity of 10 ft/sec at average effluent flowrate (i.e., 13 mgd). This discharge velocity (in excess of ambient velocity) entrains surrounding Lake Michigan water to effectively mix the effluent within a turbulent local environment.

<u>327 IAC 5-2-11.4(b)(4)(A)(iii) - For sources discharging to the open waters of Lake Michigan, define the location at which discharge-induced mixing ceases.</u>

The diffuser will be located in the open waters of Lake Michigan. Discharge-induced mixing ceases at the edge of the CORMIX2 DIMZ, which is equivalent to the edge of the Near-Field Zone where plume velocity approaches ambient lake velocity. For the model application chosen to simulate initial mixing, plume velocity was not given as a function of distance from the diffuser. However, based on the research references used to develop the model equations, the length of the DIMZ can be defined as one-half to one diffuser length downstream from the diffuser. For the 90-ft diffuser, this corresponds to a DIMZ distance of 45 to 90 ft. Amoco proposes a DIMZ distance of 50 ft as a conservative value consistent with the appropriate means to delineate a mixing zone.

In practice, the exact location where discharge-induced mixing ceases will depend on the magnitude and direction of the wind-induced lake velocity. To accommodate all potential lake current directions a mixing zone that surrounds the entire diffuser is proposed. For this mixing zone, this corresponds to a 0.39 acre area shaped like a “racetrack” that is 50 ft from all points from the diffuser (see Figure 3-1).

327 IAC 5-2-11.4(b)(4)(A)(iv) - Document the physical including substrate character and geomorphology, chemical and biological characteristics of the receiving waterbody, including whether the receiving waterbody supports indigenous, endemic or naturally occurring species.

Information about the southern part of Lake Michigan has been published in numerous studies. Attachment 5 is a bibliography of technical documents relevant to this part of the lake. From a limnological basis, the deeper waters of Lake Michigan (typically termed "open waters" by limnologists) begin about 5 miles offshore in the southern part of the lake and respond to several physical forces (i.e., wind, thermal convection) which, in turn, affect the chemical and biological characteristics. Nearshore waters are most affected by local winds and shoreline and topographical features. These differences mean that the nearshore waters often have different physical, chemical, and biological characteristics than the deeper open waters. Studies within the nearshore zone, especially along the Indiana shore, likely provide more accurate information that may readily be extrapolated to the Amoco site.

Lake Michigan General Characteristics. Several studies have been conducted to characterize the circulation and transport of Lake Michigan waters. The causes and characteristics of Lake Michigan currents are dependent upon the location within the lake. Snow (1974) describes the primary causes of lake transport in the open (deep) waters (away from shore), such as wind forces, thermal convection, and Coriolis forces (rotation of the Earth). Other general lakewide influences include density gradients, weather patterns, and precipitation.

The open waters of Lake Michigan respond to general seasonal transport patterns. Thermal convection (vertical stratification) is a significant seasonal influence on general lakewide mixing and refers to the tendency of lakes to form distinct temperature layers. Stratification is typically observed in summer and winter. During summer, the surface waters, warmed by the sun, become less dense than the cooler, deeper waters. A boundary, known as a thermocline, separates the bottom waters from the surface waters. Algal photosynthesis in the upper, sunlit layer (the epilimnion) may alter the water chemistry, increasing dissolved oxygen levels, and decreasing the level of carbon dioxide and algal nutrients. Biological respiration and excretion below the thermocline (in the

hypolimnion) tend to decrease dissolved oxygen levels and increase levels of carbon dioxide and nutrients. This stratification usually ends in autumn when the surface layer cools and the entire water column can more easily be mixed. During winter, another stratification may be established with the cooler waters on top of the lake and the warmer water below. This type of stratification ends in spring. An important feature of this stratification is the seasonal availability of nutrients, particularly in spring, which can encourage blooms of algae and their consumers, the zooplankton.

Lateral mixing of open waters results in observable lake currents. Baumgartner (1968), in conjunction with the Great Lakes Region of the Federal Water Pollution Control Administration (FWPCA), presented the results of field studies to define the general open water currents in Lake Michigan. The investigators found that currents do exist in the lake with complex interrelated flow patterns. Dr. Baumgartner testified: "[currents] vary in direction and magnitude from surface to depth, from length to width, and from side to side. The variability in time is significant on a seasonal basis, but important variabilities are also observed in shorter periods of time, such as days or even hours. Superimposed on the hourly variation is a continuous process of turbulent mixing of small parcels of water." Mortimer (1975) notes that the FWPCA report "does indeed present diagrams of average circulation for various seasons, depths, and wind regimes, but they are of little use for day-to-day prediction, because of overriding effects of short term fluctuations (internal waves and responses to local winds) and of the spatial complexity of these motions, particularly near shore."

Hence, in developing information for modeling dispersion of a discharge into the nearshore south end of Lake Michigan, there could be multiple influences on lake currents, of which one is wind induced. For a specific nearshore site (e.g., S3500), mixing dynamics could be more influenced by conditions near the area than the general lake-wide circulation. Thus in the CORMIX2 modeling, velocity data was reviewed specific to the area of the proposed diffuser to corroborate the use of wind-induced velocity as a transport mechanism at S3500.

To describe the biological characteristics of the receiving waters, Amoco implemented a Lake Michigan Biomonitoring Program in May 1994 within the area of the proposed diffuser to further evaluate limnological attributes of the nearshore zone and receiving water in

support of Volume II of August 1994. Biomonitoring activities have continued since May 1994 up to and including April 1997. The Biomonitoring Program was designed to document the physical, chemical, and biological components of the receiving water, confirm the observations presented in Volume II (August 1994), and provide information to further characterize Lake Michigan at the proposed diffuser location. Key findings of the Biomonitoring Program that address 327 IAC 5-2-11.4(b)(4)(A)(iv) are presented below for the receiving water and supported by the Biomonitoring Program Database and Summary Report included as Attachment 6.

Nearshore Physical Characteristics. Nearshore lake currents, such as those encountered at the proposed Amoco diffuser site, are caused primarily by localized winds, with less influence from thermal convection or Coriolis forces. Vertical temperature stratification is seldom observable in the shallower depths and, if present at all, not maintained for long periods. As evident from direct measurements at the study sites, the temperature, pH, dissolved oxygen, and specific conductivity profiles are uniform over the 28-ft depth with no direct gradient influences expected. Coriolis forces require travel distances much larger than the delineated mixing zone to be of any consequence to overall transport.

Boundary effects due to shore and topographical features also dominate lake currents in the nearshore area. Nearshore currents will mainly follow the general direction of the wind and, in the instance of the wind blowing toward the shore, the lake water will deflect to follow the shoreline. Wind forces of sufficient duration induce ambient velocities throughout the water column in shallow lake areas, such as the beach zone near Amoco's existing Outfall 001 discharge thereby increasing the mixing.

Direct measurements of lake currents near the southwest Lake Michigan shoreline were made during tracer studies performed by Argonne National Lab in the 1970s. Saunders, et al. (ANL, "Nearshore Currents and Water Temperatures in Southwestern Lake Michigan (June - December, 1975)"), conducted continuous current measurements at five mooring stations located at mid-depth approximately five miles offshore of south Chicago. Currents in the region were predominately parallel to shore. As an example of typical results, the net motion of the water during November 17 to December 22, 1975 was toward the southeast,

but at least 11 major current reversals occurred during this period. The average currents ranged from 0.15 to 0.30 m/sec with maximum observations of approximately 1.0 m/sec. Other current measurement studies are presented in Table 2-4.

Beach dune areas with gently sloping shores characterize the general lakeshore of the Indiana portion of Lake Michigan. Snow (1974) described the major substrate component of the nearshore Calumet area as comprised of sand. Bottom sediments can be resuspended from wave action and storms, as indicated by increased turbidity of nearshore waters during these events. Ayers (1967) also described the sediments of the southwestern corner of the lake to range from silty sand to till, with fine to coarse sands covering most of the area.

Amoco studies show that the substrate of Lake Michigan in the vicinity of the proposed diffuser is a flat plane of less than one percent slope that consists of 76 percent sand, 21 percent silt, and 2 percent clay. Gravel or larger sized particles are widely scattered and typically not encountered. Particle size distributions, presented in Attachment 6, reveal a mottled distribution of silty sand substrates ranging from 49 to 90 percent sand material. Divers have observed that the surface of the sand substrate exhibits surge (oscillation) ripples that are formed in response to wind direction and surface wavelength patterns. The oscillation ripples change in direction and form when bottom wave velocity is less than 0.76 m/sec and water surface wavelength is greater than twice the water depth. The ripples at the study sites typically exhibit a straight orientation over the transect distance observed at the study site (1,500 ft) and follow expected patterns of wave refraction from shoreline obstructions and wind direction (divers' observations). Surface ripples at the study sites have been observed to be from 2 to 4 inches in height and 3 to 10 inches from crest to crest and may change daily (divers' observations).

In summary, the proposed diffuser site is located in the nearshore zone of southern Lake Michigan approximately 3,500 ft from the shoreline in a relatively flat plain of sand-dominated substrates susceptible to disruption and re-arrangement by surface induced turbulence. The diffuser site does not encroach upon any navigation channels (nearest approximately 6,080 ft distance), docks (closest fishing pier 4,200 ft away), harbors (closest boat ramp and harbor approximately 5,125 ft away), or water intakes (closest water intake 1,640 ft away).

Key findings about the physical characteristics at the proposed diffuser site determined from the Biomonitoring Program and discussed in Attachment 6 include the following.

1. Water column measurements at this site indicate complete vertical mixing over the 28 ft depth.

2. Stratification of the water column due to temperature or density has not been observed and likely does not occur.

3. Bottom substrates consist mainly of sand (76 percent) and silt (21 percent) sized particles.

4. Bottom substrates are frequently moved and re-arranged by currents and wave action resulting from storms and other water surface turbulence.

Nearshore Chemical Characteristics. The chemical water quality of the proposed diffuser site is consistent with expected nearshore conditions for southern Lake Michigan. The biomonitoring program field studies showed no significant concentration gradients were present within the water column at the proposed diffuser site. General water quality parameter concentrations determined in the field indicate characteristics of oligotrophic to mesotrophic water quality conditions, fully oxygenated fresh water of low to moderate conductivity, neutral pH, and typical seasonal temperatures. Water chemistry parameters determined from laboratory analyses of water collected at the study sites are presented in Attachment 6. The water chemistry data is consistent with USEPA STORET monitoring data (1982-1995) for many parameters for the Whiting Water Intake Crib. A STORET inventory retrieval with summary statistics is given in Attachment 7.

The receiving water quality and water chemistry conditions at the proposed diffuser site were consistent with IDEM defined background concentrations monitored at the Whiting Intake (see Table 1-4). These background concentrations are based on Lake Michigan monitoring data and indicate that the lake has an assimilative capacity for many constituents without exceeding the Indiana Water Quality Standards.

Key findings for chemical characteristics at the proposed diffuser site determined from the Biomonitoring Program and discussed in Attachment 6 include the following.

1. Water quality attributes measured in the field and observed water chemistry concentrations reflected the oligotrophic to mesotrophic conditions in the region of the proposed diffuser site.

2. General conditions include high dissolved oxygen concentrations, neutral pH, low nutrient concentrations, and normal seasonal temperature fluctuations.

3. Secchi disk (transparency) depths were more dependent upon effects from local wind patterns and storms than chlorophyll-*a* concentrations which were frequently less than 1.0 milligram per cubic meter.

4. Water chemistry parameters did not indicate thermal stratification of the water column or show horizontal variation in concentration.

Nearshore Biological Characteristics. The extreme southern end of Lake Michigan has been generally classified as mesotrophic (Great Lakes Water Quality Board, 1977). This trophic status is intermediate between oligotrophic (clear water, low nutrient concentration, low biological productivity) and eutrophic (nutrient rich, highly productive). The mesotrophic classification was based on four criteria: phytoplankton, zooplankton, chlorophyll-a, and total phosphorus.

The biological characteristics of the receiving water at the proposed diffuser site are controlled by the natural physical settings. The flat, sandy bottom and naturally constant turbulence combine to exhibit characteristics of a flooded beach. These conditions result in a physically unstable habitat which, combined with fluctuations due to seasonal factors, limit the potential for developing a complex biological ecosystem. Few ecological studies have been conducted previously of this physically unstable "beach water zone" defined as less than 30 ft depth and less than two miles offshore (USFWS, 1970).

Amoco's Lake Michigan Biomonitoring Program was based on the concept that the most exposed communities would be most appropriate to measure (Figure 3-3). Additional focus was directed toward sessile and drifting organisms because of the greater potential for exposure to effluent from a fixed-point discharge. Biomonitoring results presented in Attachment 6 indicated that the phytoplankton drifting assemblage included numerous tychoplanktonic algae (taxa that persist in the water column but more commonly grow

attached to a substrate) that were likely re-suspended from the bottom surface. The assemblage of phytoplankton and zooplankton taxa were consistent with expectations for southern Lake Michigan, though their presence and distribution was likely determined primarily by wind-induced lake currents. Benthic (sessile) organisms in particular showed low density and species richness. The frequent disruption of the lake bottom from storms and surface turbulence within the beach water zone effectively created shifting sand substrates that limited complex benthic community development and productivity. Fish were seldom observed at the study sites[9].

Key findings for biological characteristics at the proposed diffuser site determined from the Biomonitoring Program and discussed in Attachment 6 include the following:

1. Fish are not common at the study site. A lack of habitat structure, refugia, and food resources prevent the diffuser location from attracting high numbers of fish. Fish observed in the environs of the study site include non-native gobies and alewives.

2. The benthos assemblage exhibits low richness, low diversity, and a patchy distribution with respect to species and abundance.

3. Spatial and temporal variability of the benthos assemblage was high.

4. Frequent bottom surface disturbances from surface water wave action limits development of a complex benthos assemblage. Organisms that burrow into the substrate to avoid abrasion from shifting sands (oligochaete worms) or hard-shelled organisms (snails, clams, and mussels) that are more protected from abrasion appear to be most common.

5. The phytoplankton assemblages contain green algae, yellow-green algae, and diatoms, flagellates and blue-green algae forms. Diatoms dominate the assemblage. Tychoplanktonic algae re-suspended into the water column from the sediment surface were common. Richness and diversity of the phytoplankton were higher than benthos or zooplankton because of the tychoplanktonic nature of this community.

6. The zooplankton assemblages exhibited low richness and low diversity. The zooplankton assemblage consisted of rotifers, cladocera and copepods. Dominant organisms included the copepod *Diacyclops bicuspidatus thomasi*, *Diaptomus* sp. and *Mesocyclops edax*, and the rotifer *Asplanchna herricki*. Abundance of these organisms was highly variable and reflected a highly patchy distribution.

[9] A summary of representative fisheries obtained from USFWS (1996) is presented in Attachment 8.

7. Low values for fish abundance, phytoplankton and zooplankton density, Secchi disk depth, and chlorophyll-a concentrations were consistent with characteristic of oligotrophic to mesotrophic conditions for Lake Michigan at the proposed diffuser site.

<u>327 IAC 5-2-11.4(b)(4)(A)(v) - Document the physical, chemical, and biological characteristics of the effluent.</u>

The Amoco Outfall 001 effluent is freshwater with a temperature greater than the receiving water, thereby resulting in a positively buoyant discharge plume. The long-term average effluent flow rate is 13 mgd and the multiport diffuser is designed to maintain a port exit velocity of 10 ft/sec at this average flow rate. The diffuser will be designed to operate and provide suitable dispersion over an effluent flow range of 7 to 44 mgd. This is the range of short duration flows observed over three years (1991-1994). Chemical and biological characteristics of Outfall 001 are presented in Volume I Form 2C Part V and Part VII of this NPDES Permit Application. There are two major observations regarding effluent quality: 1) all maximum bioavailable concentrations of constituents are below the Indiana acute aquatic criteria; and 2) based on three years of effluent toxicity biomonitoring using standard USEPA methods and procedures, no acute toxicity has been measured or observed for the 001 effluent.

<u>327 IAC 5-2-11.4(b)(4)(A)(vi) - Document the synergistic effects of overlapping mixing zones or the aggregate effects of adjacent mixing zones.</u>

No mixing zones from other local discharges are located within or adjacent to the proposed Amoco diffuser mixing zone. The Amoco mixing zone will not contact the Lake Michigan shoreline or encroach upon drinking water or industrial intakes. The 0.39 acre mixing zone, which is 50 ft from all points on the diffuser header is about 3,500 ft from the current Outfall 001 side channel discharge.

<u>327 IAC 5-2-11.4(b)(4)(A)(vii) - Show whether organisms would be attracted to the area of mixing as a result of the effluent character.</u>

The effluent character will remain the same as currently discharged from Outfall 001. Temperature differences between ambient lake water and the effluent may attract fish.

The dispersion modeling estimates used an annual temperature differential of 20° C between effluent and ambient receiving water. However, heat dissipation through the 3,500-ft pipe and rapid mixing at the diffuser will reduce the temperature differential that currently exists at Outfall 001. The 10 ft/sec exit velocity at the diffuser ports will effectively create an "avoidance zone" immediately near the diffuser because of the excess energy expenditure required of fish to persist at this location. The proposed diffuser configuration and associated rapid mixing provides a smaller area of attraction than currently exists at outfall 001.

<u>327 IAC 5-2-11.4(b)(4)(B)(i) - The mixing zone would not interfere with or block passage of fish or aquatic life.</u>

The mixing zone will not interfere with or block passage of fish or aquatic life. No migratory routes or preferred passages for fish or benthic organisms capable of self-dispersion are known to exist in the proposed mixing zone area. The mixing zone will not interfere with or block passage of aquatic life dependent upon dispersion by currents and wave action. The size of the mixing zone delineated from the proposed diffuser (0.39 acre, 50 ft from all points on the diffuser header) is minimized to provide rapid and complete mixing within a small area. Since the mixing zone will be located in an area unconfined by immediate shoreline or other structures (3,500 ft from the current Outfall 001) and does not contact any shoreline, no obstruction of any migratory routes or passage of any indigenous aquatic species, including fish, can occur. The 90-ft diffuser header located on the lake bottom will also not be an obstruction to any migratory routes of any indigenous aquatic species.

<u>327 IAC 5-2-11.4(b)(4)(B)(ii) - The level of pollutant permitted in the waterbody would not likely jeopardize the continued existence of any endangered or threatened species listed under Section 4 of the ESA or result in the destruction or adverse modification of such species habitat.</u>

The level of pollutant in the waterbody will not jeopardize the continued existence of any endangered or threatened species or result in the destruction or adverse modifications to endangered or threatened species' critical habitat. Based on Indiana rules, there are no bioaccumulative chemicals of concern (BCCs) in the effluent, nor is the mixing zone

proposed for BCCs. Threatened and endangered species that are recognized under Section 4 of the ESA ths\at occur in Indiana are presented in Attachment 9. Organisms that can occur in the nearshore zone of Lake Michigan that may encounter the mixing zone include birds, fish, crustaceans, mussels, and gastropods. No fish, crustaceans, or gastropods listed for the State of Indiana are indicated as federally recognized endangered or threatened species. The mussels identified as federally threatened or endangered are supported by critical habitats that exist in flowing waters. The proposed mixing zone would not be considered a critical habitat or critical food resource for bird species listed for northern Indiana, which include Peregrine falcon, bald eagle, and interior least tern.

327 IAC 5-2-11.4(b)(4)(B)(iii) - The mixing would not extend to drinking water intakes.

The Amoco mixing zone will not encroach upon drinking water or industrial intakes. The 0.39 acre mixing zone, which is 50 ft from all points on the diffuser header will be about 1,640 ft northeast of the City of Whiting/Amoco intake. The diffuser ports will discharge to the north towards the center of the lake. Amoco Outfall 001 effluent currently meets primary drinking water standards.

327 IAC 5-2-11.4(b)(4)(B)(iv) - The mixing zone would not impair or otherwise interfere with the designated uses of the receiving water or downstream waters.

Indiana Water Quality Standards are applied to protect and maintain the designated uses of waters of the state, including Lake Michigan. Lake Michigan is designated for uses as: a public, industrial, and agricultural water supply; full-body-contact recreation; and support for a well-balanced aquatic community. The water quality criteria (numeric and whole effluent) presented in 327 IAC 2-1.5-8 are based on protecting these uses of the water. Water quality standards given in 327 IAC 2-1.5-8 shall apply as defined by their in-stream derivation at appropriate points based on time, exposure, duration, and frequency. Attainment of the water quality standards at their appropriate points assures continued all designated uses of the waterbody. Amoco's mixing zone will not impair or interfere with the designated uses of Lake Michigan.

Lake Michigan is also used as a source of water for drinking water treatment plants. The nearest point of water intake is the Whiting intake located approximately 1,640 ft from the proposed diffuser. The mixing zone extends only to a distance of 50 ft from the diffuser. For those substances with primary drinking water standards, which are human health safety-based, as established by the Federal Safe Drinking Water Act, Outfall 001 maximum effluent concentrations are already less than these drinking water standards at end-of-pipe (prior to mixing with Lake Michigan) as presented in Table 3-1. In other words, Outfall 001 effluent contains smaller quantities of these substances than the concentrations given as the federal primary drinking water standards. Thus, Amoco's projected mixing zone will not adversely affect Lake Michigan as a source of drinking water.

327 IAC 5-2-11.4(b)(4)(B)(v) - The mixing zone would not promote undesirable aquatic life or result in a dominance of nuisance species.

The mixing zone is not expected to promote undesirable aquatic life or result in a dominance of nuisance species. With the exception of a beneficial reduction in area for mixing with receiving water, the character of the effluent will not change from current Outfall 001 conditions. The promotion of undesirable planktonic or benthic aquatic life, or dominance of nuisance species has not been observed, detected, or documented for the existing effluent discharge from Outfall 001. Increases in resident species or introduced exotic organisms that could possibly attain undesirable or nuisance status would likely result from changes in lake-wide water quality or biological dynamics, and not from the Outfall 001 mixing zone.

Indiana-specific nuisance and non-indigenous species information was unavailable; however, organisms listed as Species of Concern in the Nonindigenous Aquatic Nuisance Species State Management Plan (State of Michigan DEQ 1995) that have been observed or recorded at the proposed mixing zone site are the round goby fish and zebra mussel. The planktonic spiny water flea has not been recorded at the proposed diffuser site and distribution of the spiny water flea is dependent upon lake currents. The round goby fish has been observed after storm events feeding upon amphipod crustaceans associated with tangles of unattached organic debris transported along the lake bottom. It is anticipated that the mixing zone will have negligible effect on the occurrence or distribution of unattached organic debris along the lake bottom. Zebra

mussels typically occur on occasional woody debris or small stones that can provide a solid substrate. The construction of the diffuser header and feeder pipe will cause a modification to the lake bottom substrate as the pipeline trench is backfilled and stabilized with rip-rap or similar material that may provide a firm substrate for zebra mussel colonization. It is anticipated that areas of firm substrate exposure will be limited as transport of sand substrate will cover the habitat, hence minimizing overall zebra mussel colonization. The character of the effluent and mixing zone, though, will not promote zebra mussel growth over and above current lake conditions and habitat limitations.

327 IAC 5-2-11.4(b)(4)(B)(vi) - By allowing the additional mixing: (AA) substances will not settle to form objectionable deposits; (BB) floating debris, oil, scum, and other matter in concentrations that form nuisances will not be produced; and (CC) objectionable color, odor, taste, or turbidity will not be produced.

The current Outfall 001 side channel discharge is subject to provisions in the NPDES permit whereupon: (AA) substances will not settle to form objectionable deposits; (BB) floating debris, oil, scum, and other matter in concentrations that form nuisances will not be produced; and (CC) objectionable color, odor, taste, or turbidity will not be produced. The current Outfall 001 complies with this permit stipulation. The effluent character from the proposed diffuser will not change from the current Outfall 001 discharge. Therefore, it is anticipated that the discharge from the diffuser will meet the following conditions: (AA) substances will not settle to form objectionable deposits; (BB) floating debris, oil, scum, and other matter in concentrations that form nuisances will not be produced; and (CC) objectionable color, odor, taste, or turbidity will not be produced.

327 IAC 5-2-11.4(b)(4)(C) - In no case shall a mixing zone for a discharge into the open waters of Lake Michigan be granted that exceeds the area where discharge-induced mixing occurs.

As presented above, the Outfall 001 diffuser will be a discharge to the open waters of Lake Michigan. The applicable mixing zone dispersion is capped to where discharged-induced mixing ceases. Discharge-induced mixing ceases at the edge of the CORMIX2 DIMZ, which is equivalent to the edge of the Near-Field Zone where plume velocity approaches

ambient lake velocity. Therefore, the applicable mixing zone dispersion and distance are reduced to the corresponding DIMZ values (54:1 and 0.39-acre mixing zone 50 ft from all points on the diffuser header).

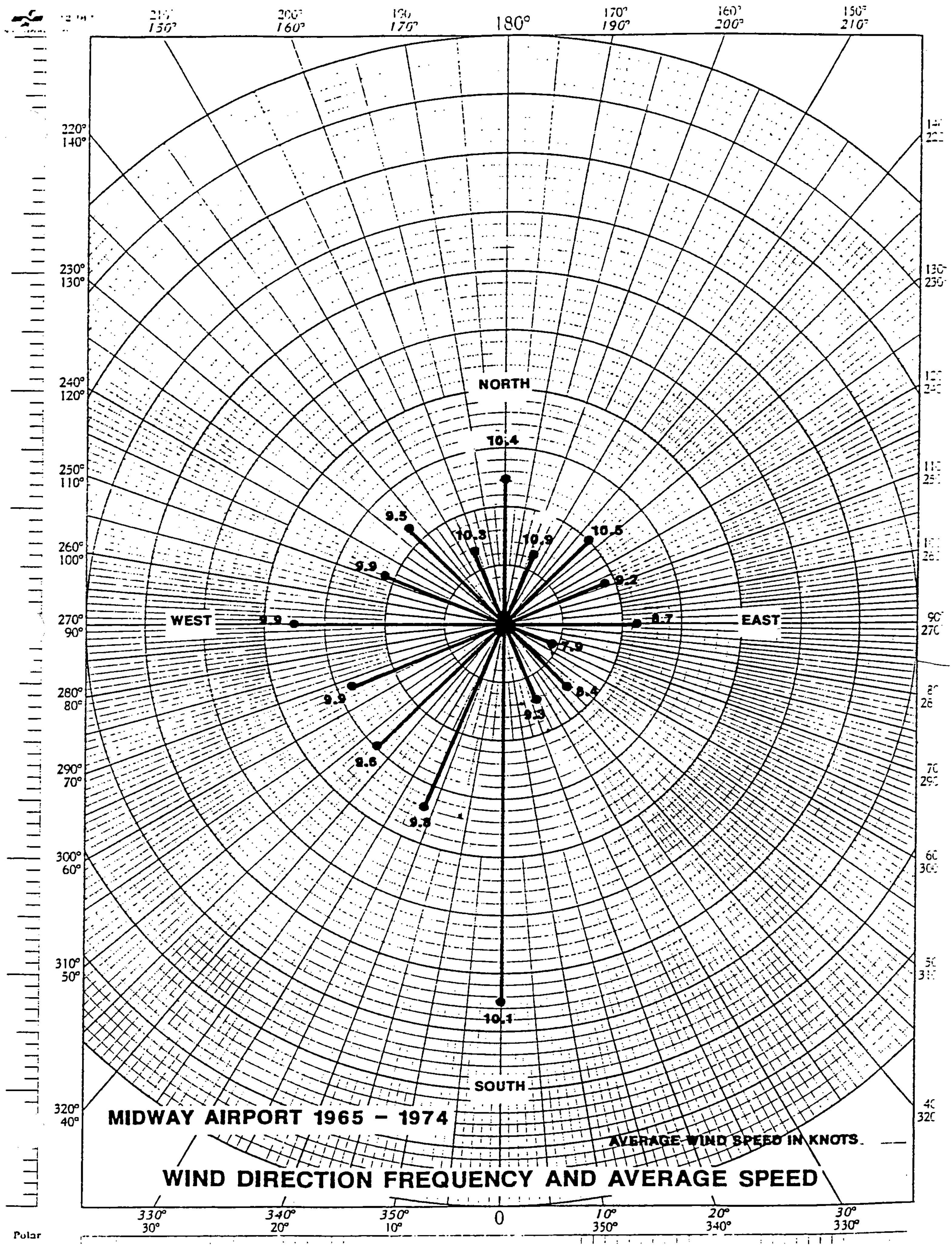
3.3 OVERALL SUMMARY

The background information on Lake Michigan, the recent biological studies of the proposed Amoco multiport diffuser site, and compliance with state regulations and federal mixing zone guidelines all demonstrate that implementation of a mixing zone is appropriate for Outfall 001.

ATTACHMENT 3

WIND ROSE

(No change from Volume II, August 1994)



NORTH
SOUTH
WEST
EAST
10.4
9.5
10.3
10.9
10.5
9.9
9.2
9.9
8.7
7.9
9.9
8.4
9.3
8.6
9.8
10.1
MIDWAY AIRPORT 1965 - 1974
AVERAGE WIND SPEED IN KNOTS
WIND DIRECTION FREQUENCY AND AVERAGE SPEED
180°
0

ATTACHMENT 4

CORMIX2 MODEL OUTPUT

(No change from Volume II, August 1994)

CORMIX2 PREDICTION FILE:

```
                        CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX2:                                                   Subsystem
version:
 Submerged   Multiport   Diffuser   Discharges
CMX2_v.2.10_____________May_1993
----------------------------------------------------------------------
----------------------------------------------------------------------

CASE DESCRIPTION
 Site name/label:          SITE^B
 Design case:              0.10mps
 FILE NAME:                cormix\sim\sitebv3 .cx2
 Time of Fortran run:      07/22/94--12:03:32

ENVIRONMENT PARAMETERS (metric units)
 Unbounded section
 HA     =       8.69  HD     =      8.69
 UA     =       .100  F      =      .047  USTAR = .7647E-02
 UW     =      2.000  UWSTAR= .2198E-02
 Uniform density environment
 STRCND=  U           RHOAM =  999.7019

DIFFUSER DISCHARGE PARAMETERS (metric units)
 DITYPE=unidirectional_perpendicular
 BETYPE=unidirectional_without_fanning
 BANK   =  LEFT      DISTB =   1083.70  YB1    =   1070.00  YB2  = 1097.40
 LD     =      27.40  NOPEN =   10        SPAC   =      3.04
 D0     =       .152  A0    =       .018  H0     =       .50
 GAMMA  =      90.00  THETA =       .00
 SIGMA  =        .00  BETA  =     90.00
 U0     =      3.136  Q0    =       .569          = .5690E+00
 RHO0   =   995.6470  DRHO0 = .4055E+01   GP0    = .3978E-01
 C0     = .1000E+03   CUNITS=  PERCENT
 IPOLL  =  1          KS    = .0000E+00   KD     = .0000E+00

FLUX VARIABLES - PER UNIT DIFFUSER LENGTH (metric units)
 q0    = .2077E-01  m0    = .6512E-01  j0    = .8260E-03  SIGNJ0 =  1.0
 Associated 2-d length scales (meters)
 lQ=B   =       .007  lM    =      7.38   lm     =      6.51
 lmp    =   99999.00  lbp   =  99999.00   la     =  99999.00

FLUX VARIABLES - ENTIRE DIFFUSER (metric units)
 Q0    = .5690E+00  M0    = .1784E+01   J0     = .2263E-01
 Associated 3-d length scales (meters)
 LQ     =       .43  LM     =     10.26  Lm     =     13.36  Lb   =   22.63
                                         Lmp    = 99999.00  Lbp =  99999.00

NON-DIMENSIONAL PARAMETERS
 FR0    =     193.18  FRD0  =     40.32   R      =     31.35
 (slot)               (port/nozzle)

FLOW CLASSIFICATION

 2  Flow class (CORMIX2)      =    MU2    2
 2  Applicable layer depth HS =    8.69   2
```

```
MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0     = .1000E+03   CUNITS=   PERCENT
 NTOX   =  0
 NSTD   =  0
 REGMZ =  0
 XINT   =    1000.00   XMAX   =    1000.00

X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the bottom and the diffuser mid-point:
      1083.70 m  from the LEFT  bank/shore.
    X-axis points downstream, Y-axis points to left, Z-axis points
upward.
NSTEP = 20 display intervals per module
-------------------------------------------------------------------
-------------------------------------------------------------------
BEGIN MOD201: DIFFUSER DISCHARGE MODULE


 Profile definitions:
   BV = Gaussian 1/e (37%) half-width, in vertical plane normal to
trajectory
   BH = top-hat half-width, in horizontal plane normal to trajectory
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)

       X         Y         Z         S        C        BV       BH
      .00       .00       .50       1.0   .100E+03    .01     13.70

END OF MOD201: DIFFUSER DISCHARGE MODULE

-------------------------------------------------------------------
-------------------------------------------------------------------
BEGIN MOD271: ACCELERATION ZONE OF UNIDIRECTIONAL CO-FLOWING DIFFUSER


 In this laterally contracting zone the diffuser plume becomes VERTICALLY
FULLY
  MIXED over the entire layer depth (HS =    8.69m).
   Full mixing is achieved after a plume distance of about five
   layer depths from the diffuser.

 Profile definitions:
   BV = layer depth (vertically mixed)
   BH = top-hat half-width, in horizontal plane normal to trajectory
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)

       X         Y         Z         S        C        BV       BH
      .00       .00      8.69       1.0   .100E+03   8.69     13.70
      .69       .00      8.69      54.0   .185E+01   8.69     13.35
     1.37       .00      8.69      54.0   .185E+01   8.69     13.05
     2.06       .00      8.69      54.0   .185E+01   8.69     12.79
     2.74       .00      8.69      54.0   .185E+01   8.69     12.56
     3.42       .00      8.69      54.0   .185E+01   8.69     12.36
     4.11       .00      8.69      54.0   .185E+01   8.69     12.18
     4.80       .00      8.69      54.0   .185E+01   8.69     12.03
     5.48       .00      8.69      54.0   .185E+01   8.69     11.89
     6.16       .00      8.69      54.0   .185E+01   8.69     11.76
     6.85       .00      8.69      54.0   .185E+01   8.69     11.65
```

7.53	.00	8.69	54.0	.185E+01	8.69	11.55
8.22	.00	8.69	54.0	.185E+01	8.69	11.47
8.91	.00	8.69	54.0	.185E+01	8.69	11.39
9.59	.00	8.69	54.0	.185E+01	8.69	11.33
10.28	.00	8.69	54.0	.185E+01	8.69	11.29
10.96	.00	8.69	54.0	.185E+01	8.69	11.25
11.65	.00	8.69	54.0	.185E+01	8.69	11.22
12.33	.00	8.69	54.0	.185E+01	8.69	11.21
13.02	.00	8.69	54.0	.185E+01	8.69	11.20
13.70	.00	8.69	54.0	.185E+01	8.69	11.19

Cumulative travel time = 87. sec

END OF MOD271: ACCELERATION ZONE OF UNIDIRECTIONAL CO-FLOWING DIFFUSER

BEGIN MOD251: DIFFUSER PLUME IN CO-FLOW

Phase 1: Vertically mixed, Phase 2: Re-stratified

Phase 2: The flow has RESTRATIFIED at the beginning of this zone.

This flow region is INSIGNIFICANT in spatial extent and will be by-passed.

END OF MOD251: DIFFUSER PLUME IN CO-FLOW

** End of NEAR-FIELD REGION (NFR) **

The initial plume WIDTH values in the next far-field module will be
CORRECTED by a factor 1.58 to conserve the mass flux in the far-field!
The correction factor is quite large because of the small ambient velocity
relative to the strong mixing characteristics of the discharge!
This indicates localized RECIRCULATION REGIONS and internal hydraulic JUMPS.

BEGIN MOD241: BUOYANT AMBIENT SPREADING

Profile definitions:
BV = top-hat thickness, measured vertically
BH = top-hat half-width, measured horizontally in y-direction
ZU = upper plume boundary (Z-coordinate)
ZL = lower plume boundary (Z-coordinate)
S = hydrodynamic average (bulk) dilution
C = average (bulk) concentration (includes reaction effects, if any)

Plume Stage 1 (not bank attached):

X	Y	Z	S	C	BV	BH	ZU	ZL
13.70	.00	8.69	54.0	.185E+01	8.69	17.68	8.69	.00
63.02	.00	8.69	66.3	.151E+01	4.75	39.68	8.69	3.94
112.33	.00	8.69	72.8	.137E+01	3.66	56.55	8.69	5.03
161.65	.00	8.69	77.8	.129E+01	3.11	71.15	8.69	5.58
210.96	.00	8.69	82.2	.122E+01	2.77	84.34	8.69	5.92
260.27	.00	8.69	86.4	.116E+01	2.55	96.54	8.69	6.14
309.59	.00	8.69	90.6	.110E+01	2.39	107.98	8.69	6.30
358.90	.00	8.69	94.9	.105E+01	2.27	118.82	8.69	6.42
408.22	.00	8.69	99.5	.101E+01	2.19	129.17	8.69	6.50
457.54	.00	8.69	104.3	.959E+00	2.13	139.09	8.69	6.56
506.85	.00	8.69	109.4	.914E+00	2.09	148.66	8.69	6.60
556.16	.00	8.69	115.0	.870E+00	2.07	157.91	8.69	6.62
605.48	.00	8.69	120.9	.827E+00	2.06	166.88	8.69	6.63
654.79	.00	8.69	127.2	.786E+00	2.06	175.61	8.69	6.63
704.11	.00	8.69	134.0	.746E+00	2.07	184.11	8.69	6.62
753.42	.00	8.69	141.3	.708E+00	2.09	192.42	8.69	6.60
802.74	.00	8.69	149.1	.671E+00	2.11	200.53	8.69	6.58
852.05	.00	8.69	157.3	.636E+00	2.15	208.49	8.69	6.54
901.37	.00	8.69	166.1	.602E+00	2.19	216.29	8.69	6.50
950.68	.00	8.69	175.5	.570E+00	2.23	223.94	8.69	6.46
1000.00	.00	8.69	185.4	.539E+00	2.28	231.47	8.69	6.41

Cumulative travel time = 9950. sec

Simulation limit based on maximum specified distance = 1000.00 m.
This is the REGION OF INTEREST limitation.

END OF MOD241: BUOYANT AMBIENT SPREADING

CORMIX2: Submerged Multiport Diffuser Discharges End of Prediction File